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# Inferences About Age Impairments in Inferential Reasoning

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Two experiments are reported in which specially constructed series completion tests were administered to samples of young and older adults to determine why increased age is associated with poorer performance on measures of inductive reasoning. The results indicated that young and older adults did not differ significantly in the effectiveness of processes concerned with determining simple relations, but that older adults were impaired when the relations are complex or when different problems involve alternative organizational patterns. We conclude that the poorer performance of older adults relative to young adults on tasks of this type may be due to inadequate (e.g., overly simplistic or temporally instable) relational structures for the integration of problem elements.

A reliable finding in the literature on cognitive functioning and aging is that increased age is associated with poorer performance on series completion tests of reasoning in which the task is to select an item that best continues a given sequence of elements. This finding was evident in the earliest large-scale study of the effects of aging on mental functioning (Jones & Conrad, 1933), and has been reported in nearly every cross-sectional age comparison involving the Thurstone Primary Mental Abilities Reasoning Test (e.g., Clark, 1960; Kamin, 1957; Schaie, 1958, 1983), and in a variety of studies in which some other type of series completion test has been administered to adults of varying age spans (e.g., Cornelius, 1984; Hooper, Hooper, & Colbert, 1984; Lachman & Jelalian, 1984; Sward, 1945; Willoughby, 1927). The size of these effects has also been quite substantial; results summarized in Figure 4.13 of Salthouse (1982) suggest a decline to about 70% of the 20-year-old level by age 65, and correlations with age of −.49 (Clark, 1960), −.42 (Cornelius, 1984), and −.26 (Hooper et al., 1984) have been reported. However, despite the consistency with which age differences have been reported, and the magnitude of those differences, very little is known about the reasons for the poorer performance of older adults because there have apparently been no analytical age-comparative studies of the processes involved in series completion tasks.

Several process-oriented studies of series completion tasks have been reported with subject populations consisting of college students or children (e.g., Holzman, Pellegrino, & Glaser, 1983; Kotovsky & Simon, 1973; Simon & Kotovsky, 1963; Sternberg & Gardner, 1983). This research has led to the postulation of two processes as important factors in solving series completion problems: (a) inferring the relations among elements, and (b) discovering the periodicity of the pattern of relations. That is, in order to solve a completion problem it is assumed that the subjects must determine how the elements are related to one another, and must also determine how the relational pattern is parsed into repeated units.

The two experiments reported here were designed to determine whether one or both of these processes is impaired with increased age. Specially constructed series completion problems were created to allow separate assessment of the efficiency of processes concerned with inferring progressively more abstract relations among elements and of the effectiveness of detecting different cyclical periodicities among elements. A representation of the structure of the three types of problems used in the current experiments, as well as a specific example of each, is displayed in Figure 1.

The A problems are the simplest because all of the elements are associated with adjacent elements by the same type of relation. That is, each element differs from the preceding element by the addition or subtraction of the same quantity, and thus the problem structure can be represented in terms of a single first-order relation. The B problems are somewhat more complex because the pattern consists of two alternating relations, one applying to the odd-numbered elements and the other applying to the even-numbered elements. In the example illustrated, the first, third, and fifth elements are related by a rule of +2, and the second, fourth, and to-be-generated sixth elements are related by a rule of +3. Problems in the C category are also complex, but in this case the complexity results from the pattern being evident only among the more abstract second-order relations. That is, adjacent elements are related by a quantity that systematically varies such that it is the relation among relations that determines the pattern.

Examination of the performance of young and older adults in these three types of problems may help determine whether age-related differences in the proficiency of series completion tests are attributable to inflexibility in the discovery of alternative patterns of periodicity, or to an inability to achieve the appropriate level of abstraction necessary to specify the relation among elements. If the former is the case, and older adults are impaired because of a weakness in recognizing alternative parsing arrangements of the to-be-related elements, then one would

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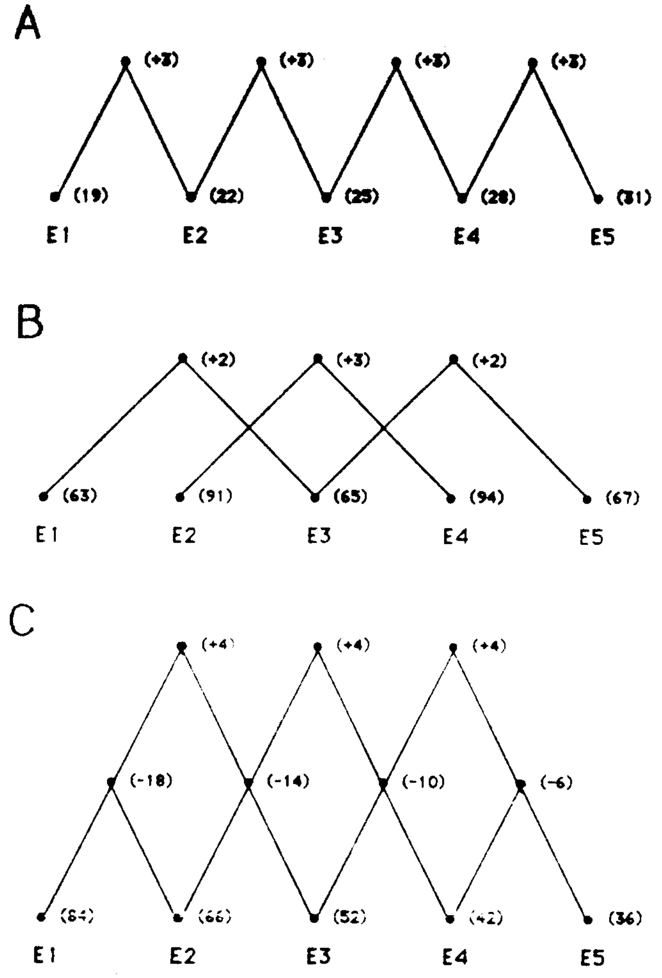

*Figure 1.* Relational structure of three types of series completion problems. (Numbers in parentheses illustrate values for a specific problem of that type.)

expect the age differences to be larger in magnitude for the B problems than for the A problems. However, if the age-related difficulty is that older adults are less efficient in achieving the requisite levels of abstraction, then the difference between their performance and that of young adults should be larger with the C problems than with the A problems. Of course, it is possible that both types of impairments contribute to the age differences in series completion performance, in which case one would expect the age differences in both B and C problems to be larger than those in A problems.

However, it is also conceivable that the age differences in series completion tasks originate for factors related to the efficiency of low-level component processes. It is therefore desirable to investigate the possibility that age differences in series completion tests occur because the older adults are less accurate in determining basic relations among elements, or in extrapolating a recognized pattern to generate the next item in the sequence. Because the elements in the present series completion problems were related by addition and subtraction, effectiveness of determining simple relations can be assessed by evaluating the accuracy of young and older adults in basic arithmetic operations of the type included in the series completion problems. Accuracy at extrapolating a known pattern to generate the next item in the sequence might be assessable by examining performance on the tasks when a representation of the structure of the pattern is presented simultaneously with the to-be-solved problem.

Some theorists have postulated that the pervasiveness of age differences across a wide variety of cognitive tasks suggests that the differences are attributable to an age-related reduction in some critical property of the entire processing system such as attentional resources, working-memory capacity, or rate of information processing. It is therefore of interest to determine the relation between series completion performance and variables that can be interpreted to reflect system-status constructs such as the capacity of working memory and the speed of information processing. The first experiment thus incorporated measures of working-memory capacity (Computational Span) and speed of information processing (Digit Symbol Substitution score) to determine whether these factors are associated with performance in series completion tests. Previous research (Salthouse, 1986) established that these particular measures are of moderate to high reliability and are extremely age sensitive, and that the Digit Symbol score is more highly correlated with other speed measures than with memory measures, whereas the reverse was true for the Computational Span score. An additional reason for selecting the Computational Span measure of working-memory capacity is that the requirement to remember the results of previous arithmetic operations while performing new operations seems very similar to what is required in the present series completion task.

## Experiment 1

The initial experiment examined the aforementioned issues by means of a number of paper-and-pencil tests. Because it was considered desirable to determine the relation between performance on the experimental series completion test and a traditional psychometric series completion test, subjects were also administered the Letter Series subtest from the Schaie–Thurstone Adult Mental Abilities Test (Schaie, 1985).

### Method

*Subjects.* Twenty-four young adults (ages 19–29, *M* age = 22.8 years) and 24 older adults (ages 56–73, *M* age = 63.9 years) participated in a single experimental session lasting approximately 1 hr. There were 16 women and 8 men in each group. Self-reported health status on a 5-point scale, ranging from *excellent* (1) to *poor* (5), averaged 1.1 in the young adults and 2.3 in the older adults, with 100% of both groups reporting themselves to be in average or better-than-average health (i.e., all ratings were 3 or lower). Years of formal education ranged from 12 to 21 (*M* = 14.3 years) among the young adults, and from 8 to 18 (*M* = 14.3 years) among the older adults.

*Procedure.* All of the subjects were tested individually and performed six tasks in the following order: (a) Digit Symbol, (b) Computational Span, (c) Letter Series, (d) Normal Number Series, (e) Patterned Number Series, and (f) Hierarchical Arithmetic. The Digit Symbol test was identical to that used in the Wechsler Adult Intelligence Scale (Wechsler, 1981), and consists of the examinee attempting to write as many symbols associated with digits as possible in 90s. As mentioned, the Letter Series test was also based on a test from a standardized test battery, in this case, the Schaie–Thurstone Adult Mental Abilities Test (Schaie, 1985). This test consists of 30 letter series completion problems, and the examinee is allowed 6 min to solve as many problems as possible.

The Computational Span test was similar to one used in Salthouse (1986), and consisted of the individual attempting to remember the last digit in simple arithmetic problems at the same time as he or she solved those problems. For example, a trial with two problems might involve the following events: the oral presentation of the first problem (e.g., 6 + 2 = ?), the subject's oral answer, the oral presentation of the second problem (e.g., 5 − 3 = ?), the subject's oral answer, and finally an instruction to RECALL, at which time the subject was to orally recall the last digit from each problem (i.e., "2" and "3"). All of the problems involved either an addition or subtraction operation and resulted in a digit different from the to-be-remembered digit in that problem. The number of arithmetic problems in the trial increased by one each time the subject was correct in at least one out of two attempts at a given sequence length. The span was identified as the longest sequence length (i.e., number of arithmetic problems) in which the subject was able to correctly perform the arithmetic operations and recall the target digits in their correct order.

The Normal Number Series test was a specially constructed paper-and-pencil test containing 40 series of five numbers each. The task for the subject was to write a number adjacent to each series that represented the best continuation of the displayed sequence. Eight of the problems were of the A type (i.e., the pattern consisted of a first-order relation), 16 were of the B type (i.e., the pattern consisted of two alternating relations), and 16 were of the C type (i.e., the pattern consisted of a second-order relation). Problems of each type were randomly intermixed among the 40 problems in the test. Only addition and subtraction operations were used in establishing relations among elements, with the operand of the first-order relations (for A and B problems), or of the second-order relation (for C problems), ranging from 1 to 4. In order to keep the B problems distinct from A and C problems, the initial numbers in the two relations differed by at least 10. Accuracy was stressed rather than time, and subjects were allowed as long as necessary to complete all 40 problems.

The Patterned Number Series test was identical to the Normal Number Series test, except that different specific problems were used and a representation of the pattern was displayed below each problem. The pattern representation consisted of the arithmetic difference between adjacent elements for the A and C problems, and the arithmetic difference between alternating elements for the B problems. For the B problems the differences between odd-numbered elements were displayed on one row below the even-numbered elements, and the differences between the even-numbered elements were displayed on a second row below the odd-numbered elements. In other words, the pattern representations were similar to the displays illustrated in Figure 1, except that no lines were presented and only the first-order relations were displayed in the C problems. As in the Normal Number Series version, accuracy was stressed rather than speed, and subjects were allowed as much time as they desired to solve the problems.

The Hierarchical Arithmetic test consisted of 24 sets of three numbers each, with the subject instructed to (a) determine the arithmetic difference between the first two numbers and write that value above them on the form, (b) determine the arithmetic difference between the second two numbers and write that number above them on the form, and (c) determine the arithmetic difference between the preceding two differences and write that number in the appropriate place on the form. (Scoring of the accuracy of the third difference was evaluated in terms of the correctness of the arithmetic based on the answers actually provided by the subject to the previous differences.) An unlimited time was available to perform this task, and accuracy was stressed more than speed.

## *Results and Discussion*

The mean scores on the Letter Series, Normal Number Series, Computational Span, and Digit Symbol tasks are displayed in Table 1, along with the intercorrelations among measures. Young adults had significantly ($p < .01$) higher scores than did older adults on each task; that is, all $t(46) > 3.50$. Only four of the correlations were significant ($p < .05$), and three of them involved Digit Symbol score as one of the variables. The low correlation between Letter Series performance and Number Series performance in the sample of young adults is rather surprising because the two tests are assumed to assess similar abilities. One factor that may have contributed to this low correlation is the restricted variability in the Number Series scores, perhaps due to a ceiling effect. Correlations with the Computational Span measure were also expected to be larger because this task was designed to involve the same type of working-memory processes as that required by at least the Number Series completion task.

One factor that may have contributed to the small correlations in Table 1 is low reliability of the measures. However, available estimates suggest that the reliability was sufficient to allow considerably higher correlations than those observed. For example, Schaie (1985) reported that the test–retest reliability of the Letter Series test over a 3-year interval was .85 for adults from 55 to 85 years of age. Salthouse (1986) found that test–retest correlations in a single session were .86 and .82 for young and older adults, respectively, with the Digit Symbol score, and .48 and .40, respectively, for a slightly different version of the Computational Span test. A true measure of Number Series reliability is not available, but results from the second experiment in this project indicate that the correlations between performance on the standard Number Series test and a similar test involving successive presentation of the elements were .63 for young adults and .71 for older adults, suggesting that the reliability was at least of this magnitude. In view of these results, it seems unlikely that the correlations are small simply because there was very little systematic variance available for association with other variables.

A possible explanation for the low correlation between performance on the Number Series and Letter Series tests in the young adult sample is that the tests emphasized different factors. For example, speed was unimportant in the Number Series test and all of the subjects had an opportunity to solve every problem, but only 6 min were allowed for the Letter Series test and many subjects were unable to attempt every problem. The structure of the problems also differed in the two tests, with number elements, addition and subtraction relations, and both sequential and alternating patterns in the Number Series test, but letter elements, mainly forward and backward progession relations, and considerable variation in parsing patterns in the Letter Series test. Any of these factors might be responsible for the low correlations between the two variables, but why they lead to such differences and why they are apparently important among young adults and not among older adults, is not yet obvious. One possibility is that factors related to processing speed

Table 1
*Correlation Matrix and Performance Summaries of Young and Older Adults in Experiment 1*

| Test | 1 | 2 | 3 | 4 | *M* Young | *M* Older | *SD* Young | *SD* Older |
|---|---|---|---|---|---|---|---|---|
| 1. Letter Series | — | .03 | .35 | .50* | 22.6 | 14.5 | 5.0 | 6.6 |
| 2. Number Series | .54** | — | .16 | .02 | 36.2 | 31.3 | 2.9 | 6.2 |
| 3. Computation Span | −.05 | .19 | — | .36 | 3.4 | 1.9 | 1.2 | 0.7 |
| 4. Digit Symbol | .66** | .43* | .08 | — | 71.5 | 46.1 | 11.2 | 9.9 |

*Note.* Summaries for young adults ($N = 24$) are above the diagonal and those for older adults ($N = 24$) are below the diagonal.
* $p < .05$. ** $p < .01$.

are specific to the speeded Letter Series task among young adults, but are important in both speed (Letter Series) and power (Number Series) tasks among older adults. The significant correlations between Digit Symbol score and Letter Series performance for young adults, and between Digit Symbol score and both Letter Series and Number Series performance for older adults is consistent with this interpretation.

Table 2 displays the mean levels of accuracy in the Normal Number Series test and the Patterned Number Series test for young and older adults in the three problem types. An Age × Test × Problem Type analysis of variance (ANOVA) revealed significant ($p < .01$) effects of age, $F(1, 46) = 12.27$; test, $F(1, 46) = 19.48$; and problem type, $F(2, 92) = 59.02$, with significant interactions of Age × Problem Type, $F(2, 92) = 11.89$, and Test × Problem Type, $F(2, 92) = 19.95$. The interactions indicate that the age differences were larger for the C (20.05%) problems than for the B (6.5%) and A (3.6%) problems, and that providing the pattern on the test resulted in greater facilitation for C (16.15%) problems than for B (0.5%) and A (2.0%) problems. However, the interactions of Age × Test, $F(1, 46) < 1.0$, and Age × Test × Problem Type, $F(2, 92) = 1.67$, $p > .15$, were not significant, suggesting that the benefits of the pattern being present were no greater for older adults than for young adults.

The failure to eliminate the age difference in performance by providing the pattern along with the problem might be interpreted as indicating that, relative to young adults, older adults have difficulty in extrapolating the correct answer from patterns that have been identified. However, the responses of some of the older adults suggested that they misinterpreted the instructions (e.g., the average accuracy in the B problems was actually lower when the pattern was provided than when it was not), and thus the conclusion that there are age differences in the accuracy of extrapolating known patterns should be considered quite tentative.

Table 2
*Mean Accuracy Across Problem Types and Age in Normal and Patterned Number Series Tests in Experiment 1*

| Number series and group | Problem type A | Problem type B | Problem type C |
|---|---|---|---|
| Normal | | | |
| Young | 99.5 | 94.8 | 81.5 |
| Old | 92.8 | 90.4 | 58.6 |
| Patterned | | | |
| Young | 98.4 | 97.4 | 94.8 |
| Old | 97.9 | 88.8 | 77.6 |

Similar levels of performance by young and older adults in the accuracy of performing the Hierarchical Arithmetic task suggest that the poorer performance of older adults in Number Series task is not simply due to less accurate determination of the relations among elements. Young adults averaged 97.8% correct answers and older adults averaged 97.0%, a difference that fell far short of statistical significance, that is, $t(46) < 1.0$. However, older adults were slightly less accurate in preserving the correct sign of the computed difference, that is, 97.2% versus 90.8%, $t(46) = 2.39$, $p < .05$. Most of this difference was attributable to a few older subjects who reversed the sign by computing differences in the wrong sequence.

A reasonable inference from the results of this first experiment is that several factors contribute to the age differences in series completion tests. Because accuracy of evaluating simple relationships in the A problems or in the Hierarchical Arithmetic task did not vary substantially across the two age groups (although a ceiling effect obviously limits the ability to detect differences), differential effectiveness of basic computation does not appear to be a major determinant of the age differences. Young and older adults did differ when the patterns were presented with the problems and the subject presumably had only to extrapolate the displayed pattern, and thus it is not possible to rule out the hypothesis that age differences are at least partly due to the effectiveness of pattern extrapolation. However, because the performance of older adults deteriorated more than that of young adults in moving from A to B, and particularly to C problems, it can be concluded that older adults have more difficulty than young adults both at detecting the periodicity of the pattern, and at carrying out the progressive levels of abstraction necessary to identify the pattern relating elements of the problem. The second experiment was designed to investigate these issues in more detail.

## Experiment 2

In an attempt to obtain a more precise specification of the processing involved in the present series completion tasks, and how that processing might differ across young and older adults, a different manner of task administration was used in the current experiment. Each series element was presented successively, with the study time controlled by the subject. Measurement of the time devoted to the processing of each element yields a duration profile for the series that should be informative about the particular kind of processing being carried out. Specific predictions can be derived from a detailed task analysis such as we will describe.

First, as each element is processed the subject can be assumed to compute the relations among elements while also trying to induce the series period. No information for determining either relations or period is available at the presentation of the first element, and consequently the processing would mainly consist of registering the element, and the study time should be relatively brief.

With the presentation of the second element, it is possible to compute the relation between the first and second elements. There would not appear to be sufficient information to infer the series period at this point. However, as we have noted, the problems were constructed such that the A problems had a small (±4) difference between the first and second elements, the C problems had a slightly larger range (resulting from either ascending or descending sequences), and the B problems a great absolute difference (magnitude of 10 or more). An astute subject might therefore not only be able to tentatively infer the series period at this point, but also to avoid computing the large difference between the first and second elements for the B problems (because this relation is irrelevant for alternating patterns). Thus, the duration for the second element might be expected to be relatively short, with perhaps a somewhat longer processing time for B problems if the constraints that were noted were not exploited.

Presentation of the third element can be seen to be a critical stage. For A problems there is sufficient information to confirm both relation and period, and the simple computations involved should result in a relatively short duration. The period of C problems can also be identified at this point, but the additional computation and memory demand required for determining the higher order relation should yield a somewhat longer duration. The duration for B problems should be strongly dependent on identification of the series period. If the subject recognizes the series as alternating, then there should be a short duration because it is only necessary to compute the relation between the first and third (current) elements and retain the second element for a separate sequence. On the other hand, if the alternating period is not determined, then a great deal of irrelevant computation would occur, resulting in a much longer processing duration for this element.

Durations for the fourth and fifth elements, and for the generation of the sixth element, can be expected to be rather similar. Durations for the A problems should remain relatively short, as it is only necessary to apply the simple relation to further elements. The last elements of the C problems should have moderate durations if the second-order relations are successfully carried out, but if intermediate results are lost or miscalculated, then longer durations would be expected as the subject continues to seek a unifying relation. Durations for the B problems should be short if the subject effectively restricts calculation of relations to alternating elements, but would be longer if the irrelevant relations between adjacent elements are computed or if difficulties are encountered in maintaining the alternating sequences.

Predictions about how young and older adults differ in these hypothesized processes depend on the assumptions one makes about the underlying causes of age differences in these types of cognitive tasks. For example, if aging is presumed to alter the effectiveness of allocating processing resources to various aspects of the task (i.e., a difference in the strategy of performing the task), then the duration profiles across successive elements for older adults might be expected to be flat, reflecting on average the same amount of processing devoted to each element and across the three problem types, rather than a selective-processing pattern like that previously described. However, qualitatively similar duration profiles might be expected if increased age is postulated to be associated with a reduction in the amount of a processing resource such as memory space, attentional energy, or rate of processing. One might anticipate the trends to be accentuated among older adults, particularly at those places where the demands for processing resources are the greatest, such as the third element for the C problems; but roughly comparable patterns of variation in duration across elements should be evident if young and older adults are carrying out the same type of processing, but with the former having more relevant resources than the latter.

Although the initial intent with the discrete presentation of elements was to let the sequence accumulate with each successive element, pilot research indicated that it was nearly impossible to encourage subjects to conduct their processing on-line when previous elements in the sequence were still visible while new elements were presented. The current study therefore used a procedure in which preceding elements were erased from the display before a new element was presented.

## *Method*

*Subjects.* Twenty-four young adults (ages 18–20, $M$ age = 18.6 years) and 24 older adults (ages 64–75, $M$ age = 67.5 years) participated in a single session ranging from less than 1 to almost 3 hr in length (depending on the individual's rate of performance). None of the individuals had participated in the previous study. There were 16 women and 8 men in the young group, and 18 women and 6 men in the older group. Self-reported health status on the 5-point scale averaged 1.5 in young adults and 1.8 for older adults, with all of the subjects reporting themselves to be in average or better-than-average health. Years of formal education ranged from 12 to 15 ($M$ = 12.5 years) for young adults, and from 8 to 22 ($M$ = 15.8 years) for older adults. Digit Symbol scores averaged 70.7 for the 22 young adults for whom scores were available, and 46.2 for the 24 older adults, $t(44) = 10.76$, $p < .01$. These data indicate that the subjects in each age group were similar to those of the previous study, and generally characteristic of the populations that have been used in previous studies of cognitive aging.

*Procedure.* Two different versions of the Number Series were implemented on a microcomputer. The normal version consisted of the simultaneous presentation of all five elements in the problem, whereas the successive version consisted of each element being presented successively, with the previous element removed from the display monitor at the time of the presentation of the next element. Implementation of the tasks on the computer not only allowed for the successive presentation of elements, but also made it possible to measure the time subjects studied each individual element. That is, the computer recorded the time an element was presented, and also the time at which the subject pressed

Table 3
*Mean Accuracy and Solution Time Across Problem Types and Age in Normal and Successive Presentation Conditions in Experiment 2*

| Presentation type and group | Problem type A | B | C |
|---|---|---|---|
| Percentage correct solutions | | | |
| Normal | | | |
| Young | 98.5 | 90.1 | 73.9 |
| Old | 92.8 | 72.1 | 50.5 |
| Successive | | | |
| Young | 97.4 | 83.8 | 68.6 |
| Old | 90.2 | 49.0 | 35.8 |
| Median time per problem (in seconds) | | | |
| Normal | | | |
| Young | 8.71 | 12.92 | 22.71 |
| Old | 15.50 | 31.11 | 50.99 |
| Successive | | | |
| Young | 9.80 | 13.71 | 22.17 |
| Old | 16.77 | 30.00 | 40.17 |

a key indicating that he or she was ready for the presentation of the next element. The difference between these two times, which can be interpreted as a measure of the duration of processing the currently displayed element, was stored for each element along with the ultimate answer typed by the subjects.

Three sets of 40 problems were constructed, with each set containing 8 A problems, 16 B problems, and 16 C problems in a randomly intermixed sequence. A given subject received one stimulus set under the normal condition, and two stimulus sets under the successive condition. All of the subjects received the normal condition before the two successive conditions, but the assignment of stimulus sets to conditions was balanced across subjects within each age group. Each condition was preceded by five practice trials illustrating the manner of stimulus presentation with each of the three problem types.

### *Results and Discussion*

Mean accuracy levels and total solution times across presentation conditions and problem types for young and old adults are displayed in Table 3. Separate Age × Condition × Problem Type ANOVAS were carried out on the accuracy and time data. All effects except the interaction of Condition × Problem Type were significant ($p < .01$) with the accuracy data. The age effect, $F(1, 46) = 32.97$, reflected the superior performance of young adults (85.4%) compared to older adults (79.7%). The condition effect, $F(1, 46) = 266.25$, reflected the superior performance in the normal (79.7%) compared to the successive (70.8%) condition. And the problem type effect, $F(2, 92) = 53.80$, reflected the ordering of accuracy from A (94.8%), to B (73.8%), to C (57.3%) problem types. The Age × Condition interaction, $F(1, 46) = 33.46$, indicated that the age difference was larger in the successive condition (25.0%) than in the normal condition (15.7%). The Age × Problem Type interaction, $F(2, 92) = 19.93$, indicated that the age differences were greater in C (28.1%) and B (26.4%) problems than in A (6.5%) problems. And finally, the triple interaction of Age × Condition × Problem Type, $F(2, 92) = 10.10$, arises because the difference between age differences in the normal and successive conditions was smaller in the A problems than in the B or C problems (see Table 3).

Comparison of performance in the normal presentation conditions in Tables 2 and 3 reveals that the older adults in Experiment 1 had higher accuracy in the B problems than did their counterparts in Experiment 2, but that otherwise the results were quite similar in the paper-and-pencil and computer versions of the tests. The similarity also extended to the correlations between Digit Symbol score and series completion accuracy as the correlations for older adults were .76 for normal presentation and .66 for successive presentation (both $ps < .01$), whereas those for young adults were .19 for normal presentation and −.12 for successive presentation (neither significantly different from zero).

Significant ($p < .01$) effects with the total time to solution variable were age, $F(1, 46) = 65.16$, older adults were slower than young adults, 30.76 versus 15.00 s; problem type, $F(2, 92) = 81.62$, solution times increased from A (12.70 s) to B (21.94 s) to C (34.01 s) problems; Age × Problem Type, $F(2, 92) = 12.10$, the age difference increased from A (6.88 s) to B (17.24 s) to C (23.14 s) problems; and Condition × Problem Type, $F(2, 92) = 5.95$, the difference between successive and simultaneous presentation increased from A (−1.18 s) to B (+0.16 s) to C (+5.68 s) problems.

Although the significant condition effects indicate that performance was generally less accurate with successive presentation of the elements, it is noteworthy that the correlations between accuracy in the normal and successive conditions were moderately high, that is, $r = .63$, for young adults, and $r = .71$, for older adults. Correlations of comparable magnitude were also evident when the number of errors on each problem were summed across all of the subjects in a given condition, and then correlations were computed across the 40 problems for a given stimulus set in the normal and successive conditions, that is, $r = .61$ to $r = .74$, for young adults, and $r = .63$ to $r = .83$, for older adults. These correlations suggest that although the successive manner of presentation accentuated the performance differences for older adults and for the B and C problems, there were still substantial similarities in the nature of the processing in the two conditions.

Profiles of the processing durations across elements in the three problem types for the young adults are displayed in Figure 2. Each point in this figure is based on the mean across subjects of each subject's median duration for correct or incorrect solutions of each problem type in the successive presentation condition. No function is portrayed for incorrect solutions to the A problems because the high accuracy (97.4%) resulted in very few relevant observations. The time represented above each element can be interpreted as the effective processing duration of that element before the appearance of the next element. For the fifth element the duration was until the appearance of a "?" indicating that an answer was expected, and for the sixth element it was the time from the occurrence of the "?" until the RETURN key was pressed to register the typed answer.

Three aspects of the data displayed in Figure 2 are worthy of comment. The first is that the profile across Elements 1 through 5 for correctly solved A and B problems is quite flat, indicating that each element was processed for about the same duration

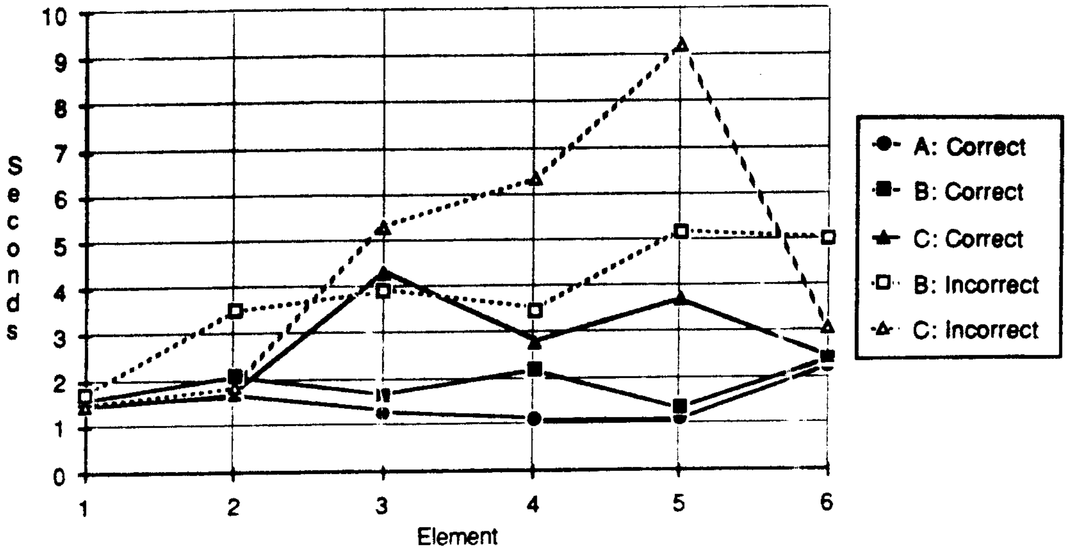

*Figure 2.* Processing durations for young adults on each successively presented element for correctly solved A, B, and C problems and incorrectly solved B and C problems.

when these problems were solved correctly. The second point is that the profile for correctly solved C problems diverges from the A and B profiles beginning at the third element. Processing time on the third element for correctly solved C problems increased by nearly a factor of three compared to preceding elements (which do not differ in duration from A and B problems), and the processing durations on the fourth and fifth elements are also inflated relative to earlier elements, or relative to the corresponding elements in A and B problems. The third interesting feature to note from Figure 2 is that the processing durations of later elements are substantially longer for B and C problems that are ultimately answered incorrectly than for those problems that are correctly solved. The differences between the durations for correct and incorrect solutions were significant ($t > 2.44$, $p < .05$) at the second through the sixth elements for the B problems, and at the third through the sixth elements for the C problems.

These results are consistent with the predictions derived from the task analysis described earlier and lead to several implications about the processing involved in the present series completion task. One implication is that the first-order relations comprising the A problems were apparently readily detected because not only was the accuracy of these problems quite high, but a relatively brief time was spent processing each element. It can also be inferred that on trials in the B problems when the subjects were ultimately correct, the alternation pattern seemed to be recognized by the second element because average processing durations were not much greater than those for the simple A problems. However, even when subjects were ultimately correct on the C problems, their processing durations were increased considerably over those for the A and B problems beginning at the third element. Longer durations for the C problems were probably not evident in the first two elements because unless the subject is sensitive to the constraint that the differences between initial elements in the alternating sequences in B problems had to exceed 10, the values of those elements would appear compatible with either A, B, or C problems. The second-order relation can be detected at the third element, however, and the additional processing required to achieve this level of abstraction would be expected to contribute to lengthy durations beginning with this element. The longer durations on the fourth and fifth elements may be attributable to the greater time needed to confirm second-order as opposed to first-order relations, and perhaps to additional time associated with rechecking what may be perceived to be relatively unusual patterns.

The most interesting aspect of the data from incorrect trials is the element at which subjects first spend more time on ultimately incorrect trials than on trials that were correctly answered. It is reasonable to expect more time to be spent on trials when the pattern is not evident and greater amounts of searching and computation are carried out, but the element at which this increased delay is first apparent indicates when the subjects first run into difficulty with that type of problem. The longer processing occurs at the second element for the B problems, suggesting that subjects are trying to detect a relation between the first and second elements that doesn't exist, and subsequently fail to recognize the alternation pattern on later elements. The delay does not occur until the third element for incorrect C problems, which may reflect the subjects devoting progressively greater amounts of time beginning with this element seeking alternative first-order or second-order relations among the preceding elements.

In order to focus on the differences between young and older adults, Figure 3 portrays the durations of the older adults divided by the corresponding durations of young adults. The mean ratio across all elements, problem types, and ultimate solution accuracy was 1.79, indicating that the older subjects spent about 79% more time than did the young subjects on each element. The two most interesting features of the data displayed in Figure 3 are that all but one of the functions were quite similar with a slight rise near the fourth element, and that the function for the correct B problems diverged from the remaining

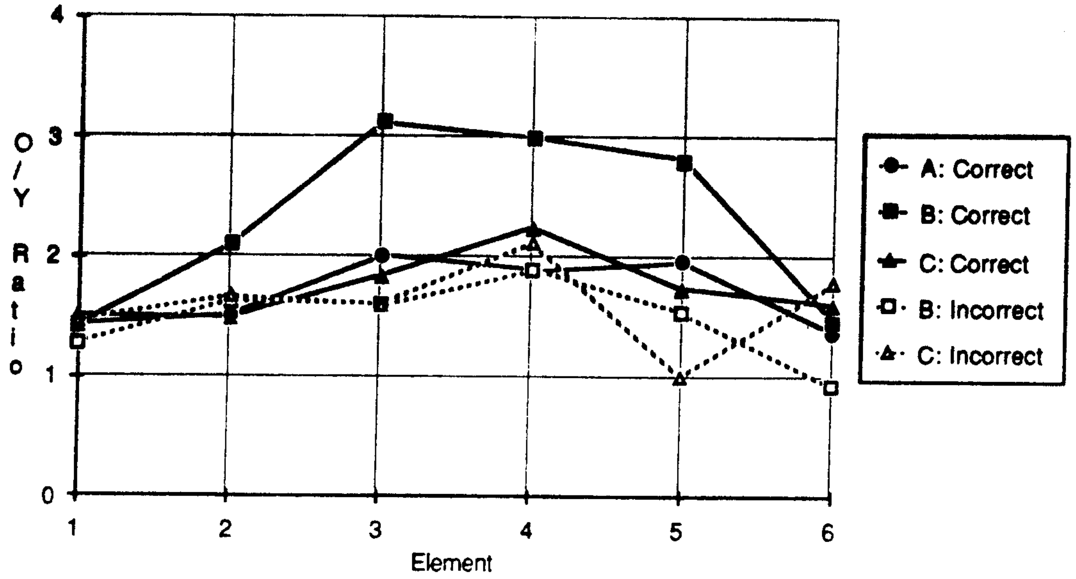

*Figure 3.* Ratio of durations of older adults to durations of young adults on each successively presented element for correctly solved A, B, and C problems, and incorrectly solved B and C problems.

functions at the second element and was consistently higher until the provision of the answer.

The relatively flat profiles for all but the correct B trials suggests that young and old adults engaged in qualitatively similar processing, although with older adults taking considerably more time at each element than young adults. The apparent increase in the functions up to the fourth element may be due to a tendency of older adults to devote more time searching for, or confirming, patterns or relations than young adults.

The inflated functions for the correct B trials resemble the profiles of the incorrect B trials in young adults, and may be attributable to older adults detecting the alternating pattern later in the sequence than young adults. That is, the functions for incorrect B problems in young adults are presumably inflated relative to correct B problems because of a prolonged and unsuccessful search for the appropriate relational structure. Older adults might exhibit this same type of extensive search on B problems even when they are ultimately solved successfully, perhaps because the odd–even structure is not detected until nearly all of the elements have been presented. However, it is important to note that older adults, like young adults, still had longer processing durations for incorrect B problems than for correct B problems.

## General Discussion

The results of the present experiments replicate the finding of sizable age differences in series completion tasks, and suggest reasons for the origin of at least some of those differences. One factor that appears to be relatively unimportant in contributing to age differences in these types of inductive reasoning tasks is the accuracy of processes concerned with computing relations among elements. Young and older adults were very similar in the effectiveness of simple arithmetic, and differed only slightly in the accuracy of solving A problems involving basic first-order relations among elements. No definitive conclusion can be reached concerning age differences in the effectiveness of extrapolating new items from known sequences because the task designed to assess competence in this ability was apparently misunderstood by some subjects and older adults performed worse than young subjects when a representation of the pattern was presented simultaneously with the problem. However, the pronounced age differences in the B and C problems, particularly in Experiment 2, suggest that increased age is associated with special difficulties in progressive abstraction and flexibility in considering alternative parsing patterns.

Poor performance in both the B and C problems could be related to an inability to process intensively enough to achieve the higher order abstractions of alternation and relation among relations. One way of conceptualizing the solution of series completion problems is in terms of building a relational structure somewhat analogous to the structures illustrated in Figure 1. That is, the subject constructs an arrangement indicating how the elements are related to one another, and when valid, this inferred structure easily guides extrapolation or continuation of the sequence. When viewed from this perspective, older adults can be characterized as building flimsier and less stable relational structures than do young adults. They seem nearly as capable as young adults in assembling basic structural units and may not differ in effectiveness of using the structures when they are available, but they appear to have greater difficulty in constructing and maintaining all but the simplest integrative structures.

What might be responsible for these types of construction deficits? Three possibilities are that the constructions are instable because (a) limitations of working memory lead to unreliable components, (b) there is insufficient attentional energy to link the components firmly together, or (c) a slower speed of operation results in the products of earlier operations disintegrating before later processing is complete.

A reduction in working-memory capacity with increased age might account for the failure to create stable relational structures because a small capacity could result in the unpredictable loss of the products of earlier processing. The discovery that the older adults had significantly smaller computational spans than young adults is consistent with this interpretation, although lack of a positive correlation with performance on the Number Series completion task is not easily explained from the working-memory perspective.

If attentional energy functions as the glue that holds components in the structure together, then a diminished quantity of these attentional resources with increased age could be responsible for the performance impairments observed in these tasks. However, it is not at all clear how this interpretation could be tested because there are apparently no operational definitions of the attentional energy concept, nor any means for inferring its existence independent of the phenomena for which it is postulated to explain. Aspects of attention have been investigated with selective and divided attention procedures, but an accepted technique for quantifying the amount of attentional energy an individual has available for processing has not yet been identified.

A third possible contributor to weak or instable relational structures is too slow a rate of information processing to keep earlier components intact while later components are being processed. That is, the structures may require dynamic refreshing, much like balls being juggled in the air, and hence the stability of the structure might vary directly with the rate of executing relevant operations. Older adults in the present studies were significantly slower than young adults in the Digit Symbol test, in overall solution time in the Number Series problems, and in the average duration spent processing each individual element in the successive presentation conditions. Moreover, score on the Digit Symbol test was positively correlated with accuracy in both of the Number Series tests in Experiment 2, with accuracy in the Number Series and Letter Series tests in Experiment 1 among older adults, and with Letter Series accuracy in Experiment 1 among young adults, indicating that faster processing was associated with greater accuracy even within an age group. The major weakness of this interpretation is that despite plausible arguments, there is not yet any direct evidence linking the speed of mental operations to the quality of products from internal processing.

Although the working-memory capacity, attentional energy, and speed of processing interpretations are conceptually independent, they may be very difficult to distinguish empirically. As we have discussed, differences in any of these entities could have similar consequences in tasks such as series completion. It is also possible that these factors are all interrelated in that sufficient attentional energy or fast execution of operations may contribute to larger capacity of working memory, greater working-memory capacity or more attentional energy may contribute to faster information processing, and larger working-memory capacity and a faster rate of processing may produce what appears to be a larger supply of attentional energy. Although it may not be feasible to determine which, if any, of these system-status factors is responsible for the age differences in series completion performance, the available evidence does seem to suggest that at least some of those differences are mediated by an inability to create and maintain abstract relational structures.

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